

F. TREBUŇA, F. ŠIMČÁK, M. BURŠÁK, J. BOCKO, P. ŠARGA, M. PÁSTOR, P. TREBUŇA

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THE STRAIN GAGE METHOD FOR DETERMINATION OF INPUT WORKING LIFE PARAMETERS OF PIPES IN COMPRESSOR STATIONS

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For determination of safety operation of compressor stations and assessment of their residual working life is necessary to know the levels of residual stresses, operational loading as well as functionality of real support elements and influence of history of previous loading. The method described in the paper was verified several times during solution of problems concerning safety operation of piping yards. The method was also verified by the numerical methods of mechanics.

Key words: residual stresses, strain gage measurement, residual working life, verification of safety operation

Metoda mjerenja tenzometrom za određivanje ulaznih parametara radnog vijeka cijevi u kompresorskim stanicama. Za određivanje sigurnosti rada kompresorskih stanica i procjene njihovog preostalog radnog vijeka potrebno je poznavati razine preostalih naprezanja, operativnog opterećenja kao i funkcionalnosti realnih pomoćnih elemenata i utjecaja prikaza prethodnog opterećenja. Metoda opisana u referatu bila je nekoliko puta verificirana tijekom rješavanja problema glede sigurnog rada stovarišta cijevi. Metoda je bila verificirana i numeričkim metodama mehanike.

Ključne riječi: preostala naprezanja, mjerenje tenzometrom, preostali radni vijek, verifikacija sigurnosti rada

INTRODUCTION

Piping yards of compressor stations in Slovak republic are in continual operation for several decades. During this time they were exposed to considerable dynamical loadings, which together with static components of loading (internal pressure, loading influences introduced during reconstructions and so on) adversely affect residual working life of piping systems and consequently safety operation of compressor stations.

The problem of verification of safety operation of piping yards of compressor stations in connection with increasing compression ratio and arising of nonstandard operational states coupled with vibration was solved in [1, 2].

In the paper attention is given to the results, which were concerned to determination of input parameters for the stress analysis in elements of piping yards. During the computation was considered static (internal pressure, loading influences introduced during reconstructions) as well as dynamic loading in compressor station.

DETERMINATION OF RESIDUAL STRESSES IN PIPE SAMPLE OF PIPING YARD

Residual stresses in material of pipe exist without loading by external forces. They are caused by technology of production or by previous loading. In general, all production technologies - rolling, pressing, welding, heat-treating and so on, produce residual stresses. In some cases, the stresses



Figure 1. Location of material sampling
Slika 1. Mjesto uzorkovanja materijala

arise during life of structure due to assembly, overloading, due to settlement of foundations or limit loads that act on integral part of structure can cause them too. Another common source of these stresses are reconstructions.

F. Trebuňa, F. Šimčák, J. Bocko, P. Šarga, M. Pástor, P. Trebuňa, Faculty of Mechanical Engineering Technical University of Košice, Košice, Slovakia, M. Buršák, Faculty of Metallurgy Technical University of Košice, Košice, Slovakia

Measurement of directions and magnitudes of residual stresses was performed on pipe sample $\Phi 720 \times 22,2$ mm (Figure 1.b) that was taken from pipe according to Figure 1.a [3]. For quantification of levels of residual stresses and for determination of their directions was performed drilling in four locations on external circumference of pipe in identical distances and in one location on internal side of pipe along axis of axial weld (Figure 2.).

The measurement locations 1 to 4 were equally spaced along circumference of pipe. Location 1 is placed on axis of axial weld, locations 2, 3, 4 are in 90 degrees interval in clockwise direction (view direction from T shape pipe to compressor). In every from locations 1 and 4 were performed three measurements (assigned as 1; 1,8; 1,9 or 4; 4,6; 4,7, respectively). Their locations are seen in Figure 2.

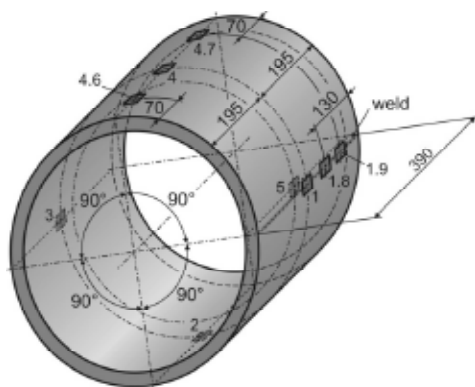


Figure 2. Location for measurement of residual stresses in pipe sample

Slika 2. Pozicije za mjerenje preostalih naprezanja na uzorku cijevi

The drilling has been performed by equipments SINT MTS 3000 (Figure 3.a) and RS 200 (Figure 3.b).

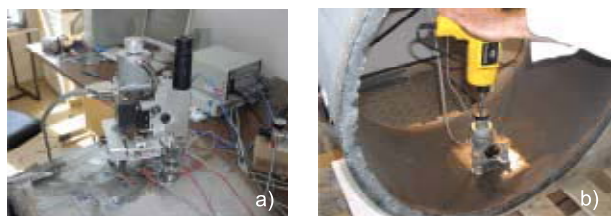


Figure 3. Equipment for drilling. a) SINT MTS 3000 in location of external weld; b) RS 200 in location of weld in internal side of pipe

Slika 3. Oprema za bušenje. a) SINT MTS 3000 na poziciji vanjskog vara; b) RS 200 na poziciji vara s unutarnje strane cijevi

For determination of residual stresses were used procedures in accordance with Standard ASTM E 837-01, Integral Method, Method of Power Series, Kockelman's method and method that uses program MEZVYNA [3, 4]. The magnitudes of principal residual stresses and their directions determined according to ASTM E 837-01 are for individual locations (Figure 2.) given in Table 1.

The magnitudes of measured values of residual stresses on the external side of pipe sample in three locations along

circumference direction (including weld) are higher than 130 MPa in circumference direction and in axial direction lie in interval 66 to 84 MPa. Because both stresses on the external side of sample have positive sign, the higher from principal stresses can be consider to be limiting for determination of fatigue failure. Declination angles of higher from principal stresses documents relatively exactly a fact that if during production the annealing was performed, than these residual stresses can be invoked only by long-term operation, overloading due to internal pressure, by pulsation or by assembly.

Table 1. Magnitudes of principal residual stresses and their directions determined according to ASTM E 837-01

Tablica 1. Magnitude glavnih preostalih naprezanja i njihovi smjerovi određeni prema standardu ASTM E 837-01

Location	σ_{\max} / MPa	σ_{\min} / MPa	φ / °
1	130	82	9
1,8	137	77	14
1,9	133	78	14
2	135	82	6,7
3	129	79	5
4	137	84	3
4,6	135	66	17
4,7	134	68	10
5	-49	-120	81

DETERMINATION OF INTEGRAL INTERNAL FORCE QUANTITIES IN CROSS-SECTIONS OF PIPE BY THE STRAIN GAGE MEASUREMENTS

The authors had used the method for experimental and numerical determination of integral internal forces quantities suggested in [5] for solution previous projects concerning compressor stations [6, 7]. With regard to the fact that was defined above, that analysis of using of increased compression ratio has to be performed, the method was arranged in order to be possible to assess critical parts in locations of high vibrations, concentrators, supports, but in the first instance for determination of boundary conditions for numerical solution. This allows expressing conclusions concerning possibilities to increase compression ratio to desired values.



Figure 4. Location of T shape pipe on the discharge pipe chosen for stress analysis

Slika 4. Pozicija T-cijevi na ispusnoj cijevi odabranoj za analizu pritiska

For investigation of stress distribution was chosen location with T shape pipe on the discharge pipe (Figure 4.).

In location of T shape pipe were applied strain gages in axial direction in virtual cross-sections A, B, C (for determination of time-dependent values of integral internal force quantities) and in axial and circumferential directions in D (for determination of stresses during prepressurization of pipe). Locations of strain gages are seen in Figure 5.a and Figure 5.b.

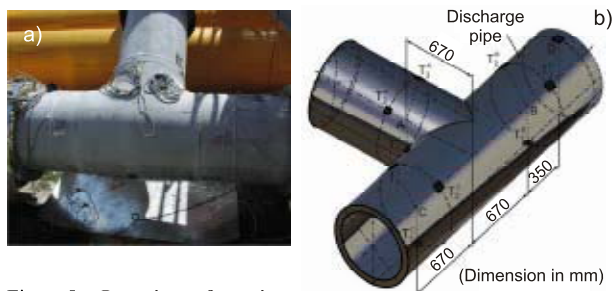


Figure 5. Location of strain gages in T shape pipe, a) perspective view; b) basic geometry; c) strain gages in location D

Slika 5. Pozicija tenzometra na T-cijevi, a) pogled iz perspektive; b) osnovna geometrija; c) tenzometri na poziciji D



The strain gages applied for virtual cross-sections in location of T shape pipe were self-compensative, type 1-LY11-10/120, series 812022215 with gauge factor $k = 2,07$, resistance 120Ω .

Though using self-compensative strain gages, because of necessity to use half-bridge, it was necessary to apply compensative strain gages on steel plates.

The strain gages were applied by two-component adhesive X60. They were connected to the wires by solder points LS4. After testing of every strain gage by tester M1300 were strain gages together with measured locations covered by insulation silicone SG-250 and in addition by insulation agent AM-75. For the strain gage measurements was used apparatus SPIDER 8.

The strain gages applied in location D (Figure 5.c) were used for measurement of incremental values of stresses in pipe during prepressurization, because as a result of exchange of spherical valve was the pipe without pressure and after reparation there were pressure $p = 6,75$ MPa.

In Figure 6. is given a chart of time-dependent increments of principal stresses in location D of discharge pipe during increasing of internal pressure from zero to magnitude 6,75 MPa.

Because in locations D1, D2 was by ultrasonic thickness gauge measured thickness of pipe wall 22,72 mm, according to the shell theory (pipe meets conditions to be

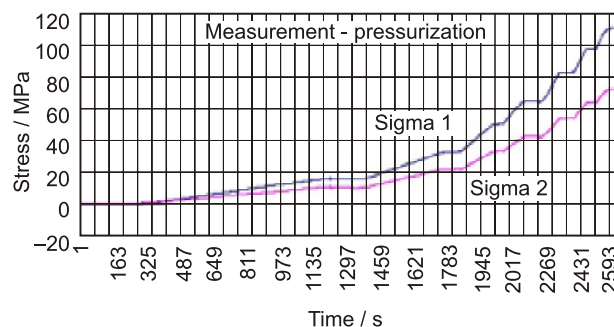


Figure 6. Dependency of principal stress increments in location D on internal pressure (pressure: 0 to 6,75 MPa)

Slika 6. Ovisnost povećanja glavnog pritiska na poziciji D na unutarnji pritisak (pritisak: 0 do 6,75 MPa)

considered as a shell) under internal pressure $p = 6,75$ MPa for the stress in circumferential direction holds [8]:

$$\sigma_0 = \frac{p \cdot D_s}{2t} = 6,57 \cdot \frac{720 - 22,72}{2 \cdot 22,72} \cong 104 \text{ MPa.}$$

Measured increment of circumferential stress for internal pressure 6,75 MPa was $\sigma_1 \cong 112$ MPa, which is value higher by approximately 7,5 % in comparison with computed stress.

According the same theory is axial stress in the shell that is closed on both ends equal half of stress in circumferential direction, which is in our case $\sigma_a = 52$ MPa.

Measured stress increment in axial direction for internal pressure 6,75 MPa is higher by 73 MPa, that is more by 40 % as a magnitude determined by simple analytical computation. It shows that simple computational methods are not suitable for determination of axial forces in pipe.

From measured strains $\varepsilon_1, \varepsilon_2, \varepsilon_3$ in locations 1, 2, 3 of thought pipe cross-sections of T shape pipe (Figure 7.) is possible to determine axial forces N , bending moments M as well as their directions (defined by angle α) in cross-sections A, B, C (Figure 5.b) during operation [5].

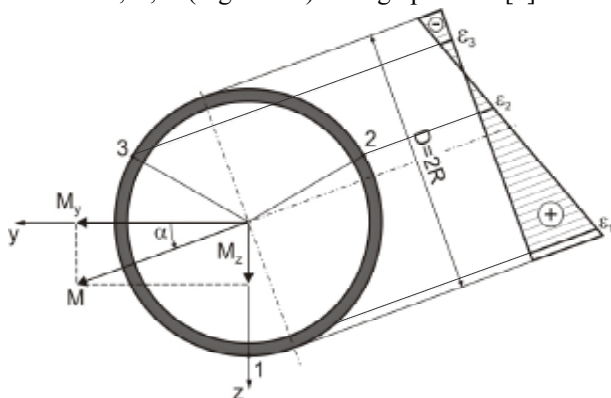


Figure 7. Strains $\varepsilon_1, \varepsilon_2, \varepsilon_3$ in directions of strain gages located in thought cross-section

Slika 7. Naprezanja $\varepsilon_1, \varepsilon_2, \varepsilon_3$ u smjerovima tenzometara lociranih na zamišljenom presjeku

In Figure 8., Figure 9. and Figure 10. are given measured time-dependent charts of strain increments, axial forces and bending moments, respectively, in individual cross-sections during operation.

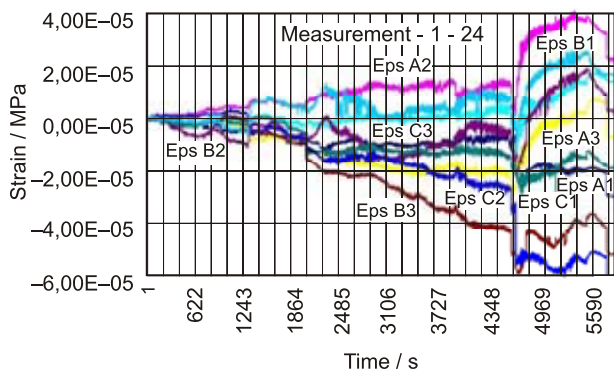


Figure 8. Time-dependent strain increments in locations A, B, C
Slika 8. Vremenski ovisna povećanja naprežanja na pozicijama A, B, C

Measured time-dependent charts of axial forces N and bending moments M in cross-sections A, B, C are further used as input data for computation of stress distribution in T shape pipe by the finite element method.

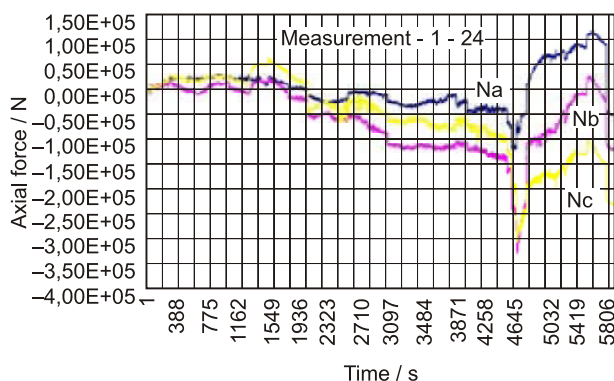


Figure 9. Time-dependent increments of axial forces in locations A, B, C
Slika 9. Vremenski ovisna povećanja osovinskih sila na pozicijama A, B, C

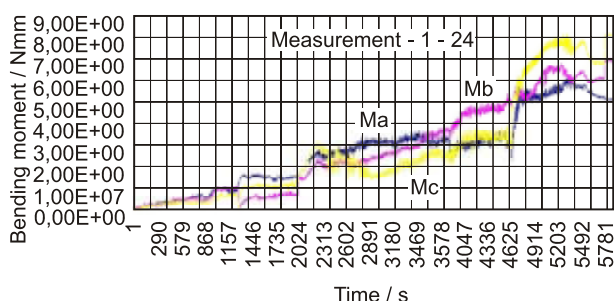


Figure 10. Time-dependent increments of bending moments M in locations A, B, C
Slika 10. Vremenski ovisna povećanja momenata svijanja M na pozicijama A, B, C

CONCLUSIONS

As follow from results given in the paper, the stresses caused by static loading are relatively high. Tensile residual stress introduced by forces reach on external surface of pipe values approximately 130 MPa in circumferential direction and 80 MPa in axial direction, while internal pressure 6,75 MPa invokes in whole thickness of pipe the stress in circumferential direction 112 MPa and in axial direction 73 MPa. The sum of values of residual stresses and stresses caused by internal pressure comprise more than 60 % of yield point value of pipe material. From these facts results that for the evaluation of working life of piping yard is necessary to take this into account by middle stress that consequently limits the amplitude of stress caused by dynamic loading. Because of this for tests of working life was chosen middle stress $\sigma_m = 250$ MPa with amplitude $\sigma_a = 90$ MPa, which is recommended in reference [9]. These magnitudes of stresses were used for fatigue tests of basic material and welded joint material of the pipe taken from piping yard as well as for complex assessment of safety of piping yards of compressor stations [1].

Measured time-dependent charts of axial forces N and bending moments M in thought cross-sections were further used as input parameters of loading for determination of stress concentrations in T shape pipe by the finite element method.

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